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JPL COMMON THREADS WORKSHOP SUMMARY REPORT

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Introduction

A Common Threads (CT) workshop was held on 31 May 1996 in the Pasadena Technical Center. The objective of the workshop was to attempt to convey some of the knowledge of seasoned Project Managers (PM) to the new generation of PMs. The premise and the theme of the workshop was that "common threads" exist which appear in program after program, in the form of similar flight and test failures and failure mechanisms, recurring programmatic issues and sometimes serious oversights. These problems are understood and often solved in some innovative way on one program, but the knowledge is frequently not passed to another program with a similar problem, and the cycle repeats.

Division 5X and NASA Code Q sponsored the CT Workshop. Attendees were experienced PMs from past spacecraft missions and PMs from a number of current programs. These were augmented by other lead personnel from current programs and representatives from the 5X organization, including retired 5X Director William Shipley. The mode of presentation was for the experienced managers to present "war stories" of incidents or issues that had occurred on their programs and the "lessons learned" which they had gained from the experience. In addition, some persons from current programs presented war stories about their own experiences in dealing with common thread problems.

Because of the format of the workshop, there was much give and take and audience participation. Discussions often moved quickly from one subject to another, and a strictly chronological presentation of the conversations would seem to lack organization. Some of the presenters spoke from view graphs; others did not. In the interest of brevity, the content of the view graphs has been incorporated into the body of this report, but the view graphs themselves have not been included. A number of participants took notes, and this report is a consolidation of all of their contributions.

As would be expected, there was not complete unanimity in the opinions voiced during the workshop, but there was substantial agreement on many issues. The approach taken in this report was to extract the common threads from all of the presenters and the discussions that followed and to present them along with the lessons learned and a few of the war stories that substantiate (or in a few cases, contradict) them. It is hoped that not too much of the spontaneity and "feel" of the workshop is lost in this consolidation process.

Summary

The presenters discussed incidents (war stories) that had occurred on their programs which had given them some deeper understanding of how things ought to be approached. Sometimes, the war stories were about specific failures or near failures that had occurred or about how they had been prevented in some way. Other war stories were told from someone's extensive experience within their discipline, such as Parts Engineering or Product Assurance.

Many “common threads” appeared in the various presentations, and they tended to fall into the following natural groupings:

Communications Issues at all Levels.	Hardware Interfaces
Contractual Interfaces	Heritage and COTS Issues
Parts Issues	Programmatic Issues
ATLO and Launch Site Issues	Product Assurance Issues

From the presentations, a number of “lessons learned” emerged. Sometimes these were stated explicitly; sometimes they were relatively obvious, and so were left unstated. To state a few of the more important lessons learned:

Communications Work on communications at all levels, i.e., within the project; between the project and the support groups such as, product assurance and safety; as well as with the contractor, subcontractor, fabrication and assembly personnel. Make sure people are properly trained to perform critical operations, and that the trained people actually perform the operations.

Interfaces Beware of interfaces of all kinds: hardware to hardware; hardware to test and ground support equipment (GSE); spacecraft to launch vehicle; and people to people. Be especially careful when a system is designed by one group and used by another. To quote Deming: “The Devil is in the hand over.”

Heritage Evaluate inherited hardware as thoroughly as you would evaluate new hardware. There is a tendency to put too much trust in inherited hardware. There were several examples in which the new spacecraft application presented life or environmental challenges not faced in the original application, and the inherited device failed. To quote Tony Spear: “No two applications are exactly alike. Something *always* changes.”

Parts Semiconductor parts are getting more reliable, but NASA and DoD programs have less control than they once did. It is becoming harder to get radiation hardened parts, and this presents new challenges such as designing-in Single Event Effect (SEE) tolerance at the system level or finding other work-arounds. Work with the Parts group early to prevent delays on long lead items. New ASIC developments are likely to be incompatible with Faster-Better-Cheaper (FBC) programs. This can be partially solved through sharing development costs and developing a strategic stockpile of qualified parts that will support a variety of new programs.

Programs There is intensive “sell” pressure on the new FBC programs to provide extraordinary levels of science and mission complexity while staying within severely constrained schedules and budgets. The mission risks are increasing, and upper management must be made fully aware of the risks involved. Provide as many spares as possible, ideally sharing spares among programs. Monitor the fundamental program assumptions and replan when fundamental assumptions change. Make sure that in the zeal to reduce costs, program reviews are long enough to be thorough. The biggest benefit of design reviews is the time spent preparing for them.

ATLO and Launch Site Issues The consensus on the correct amount of time in Assembly, Test and Launch Operations (ATLO) was somewhere between twelve and eighteen months, depending on how well people, parts and processes are understood. The new programs want ATLO to be flexible enough to add new tests as the knowledge of the hardware increases. Provide contingencies of both time and budget in ATLO to deal with the unexpected. Make sure written, well rehearsed procedures are available before going to the Cape.

Product Assurance There is a strong relationship between adequate product assurance and successful programs. As Bill Shipley stated: “Organizations have runs of “bad luck” when PA controls slacken.” He also said that “JPL is always just two failures away from being shut down.” The consensus was that there is more dependence on 5X than ever before to provide the necessary oversight on FBC programs. The projects were almost universally pleased with the new concurrent engineering/ collocated approach being used by the 5X disciplines (and especially Reliability Engineering).

In addition to war stories and lessons learned, the presenters and some of the other participants suggested some innovative ways in which the common threads could be addressed. These potential solutions tend to be incident specific and are not summarized here, but they are presented in the tables in the Discussion section.

Discussion

Tables 1 through 8 present the common threads that were discussed during the CT workshop, along with lessons learned and some approaches that the workshop participants believe to be useful in addressing them. Each table presents one of the major groups of common threads, e.g., Interfaces, Parts, or Communications issues.

The presentations ranged over many subjects, with individuals in the audience freely making comments from the floor. In a sense, the tabular format used in this report implies an order in the discussions that wasn’t really there. What has been done in the tables is to gather related comments that were made throughout the day and place them together. The intent is to capture the ideas that were presented, not to neatly resolve every issue. Nevertheless, a serious attempt has been made to deduce the implications of what was said and to write them down. The participants themselves did not always explicitly state the lesson learned or possible corrective action. Where these implications are fairly obvious, they are stated in the tables with the notation (Implied). Otherwise, the person making the statement is identified, at least as best the note takers remembered it.

There are four column headings in the tables. The definition and the general purpose of each column are described below:

Common Thread - an idea or an issue that was discussed and seemed important enough to capture. Often it was truly a “common” thread in that several different war stories on the same subject from different programs were presented. However an attempt was made to capture any significant idea presented at the workshop, either by the presenters or the participants, even if only one war story or comment was given.

War Stories - anecdotal stories related to the common thread and drawn from past or current programs. Many of these stories recount failures from previous programs and the circumstances that led up to the failures. Others are examples from current programs that describe problems in dealing with the new Faster-Better-Cheaper (FBC) guidelines or ways the projects have used to comply with them. Others simply tell how activities such as Product Assurance have been done in the past and what results occurred when policies were relaxed or tightened. In short, almost anything qualified as a war story, so long as someone was willing to tell it. Just as with real war stories, there is room for a difference of opinion. An effort was made to present all stories, even though their implications might seem to conflict.

Lessons Learned - the conclusions that can be drawn about a common thread that may have general implications for future programs. Lessons learned were not always explicitly stated by the participants, but were sometimes obvious extensions of their thought process. In these cases, the lessons learned are the writers' opinion of the implications, based on what was said. To distinguish them from the comments of the participants, they are preceded with the notation (Implied), while the comments of the workshop participants are preceded by their (Name).

Corrective Strategies - strategies or actions that can be undertaken to resolve the issues posed by the common thread. Where these are suggested actions of the participants, they are preceded by the proposer's name. Where they are the writers' extrapolation of the thought process as to what corrective strategies may be effective, they are preceded by the notation (Implied). It was considered important to write these strategies down; no apology is made for "explaining the obvious."

Numbering of Entries in the Tables

The numbers in the tables have no special significance; they only serve to separate different thoughts. Moreover, no attempt was made to use the numbers to carry thoughts on a specific topic from one column to the next. This would have added another level of complexity to the tables. It would also imply that each of the common threads and their related thought process led to some neatly resolved conclusion. This was certainly not the case, and to imply that it was so would do a disservice to the spontaneity and spirit of free interchange at the workshop.

Table 1 Common Threads - Communications

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Failure to convey "lessons learned" from one program to the next and to all program elements, including the contractor and subs.	1. (Casani) Voyager Science Boom. - One strut on the Science boom on Voyager II didn't latch. Helper springs were added to Voyager I before it was launched. The lesson wasn't learned, because on Galileo, in a somewhat analogous situation, the High Gain Antenna was built without push-off springs., and failed to fully deploy. 2. (Casani) philosophized on the "common threads" process, saying that lessons learned are "incident specific." We fix the problems and go on. We don't do the legacy. We don't carry through the lessons learned. The threads are in the interfaces, but we don't recognize where the interfaces are. 3. (Shipley) One JPL group didn't accept a formal action item to do a torque margin test. Voyager II had an indication that the Science Boom did not fully deploy and latch.	1. (Casani) The lesson learned was that in low torque situations, a positive means of providing the necessary torque should be provided. 2. (Casani) We need to draw the general conclusions and incorporate them into later programs.	1. (Casani) Consider helper springs in low torque situations. 2. (Muirhead) Pathfinder went both inside and outside the Laboratory to get "grey beard" inputs early in the program; he considered it very useful. 3.(Spear) Made the comment that it may be impossible to learn lessons; every new project crew is faced with new challenges, and it may be necessary to give the new people their head and let them make their own mistakes. 4. (Gibbel) suggested that some system like Miicrosoft Word's "tips" be used to remind people of lessons learned. This was embellished by other contributors to suggest that a system on the Internet using hyperlinks might be a good way to get new project personnel to look at related problems on older spacecraft. The hyperlinks could be set up so one would simply click on a particular feature and related historical data would be presented on the screen. The person could review it or not, but at least the data would be readily accessible. 5.(Clawson) There is a "lessons leaned" committee chaired by Jim Clawson and a summary which can be obtained from him. 6. (Barela) Fold lessons learned back into requirements. Put data into a check list for each specialty area.

Table 1 Common Threads - Communications (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Failure to convey “lessons learned” from one program to the next and to all program elements, including the contractor and subs. (Continued)	4. (Casani) - Mars Observer- Casani said that the primary suspect mode in the Mars Observer failure was anticipated on Mars Mariner. In that case they used a gas line heater and thermal blanket to make sure there wouldn’t be a condensation of leaked propellant gas. This is another case of a common thread understood and corrected by one group but not known by another group 5. Casani noted that JPL was severely chastised during the MO independent review for not conveying lessons learned to the contractor. 6. (McKinney) Magellan They lost one of four gyros during cruise, then one later. There had been a history of bearing failures before launch. This was known to the gyro supplier, but it was not known to the Magellan cognizant engineers. 7. (Casani) Scott Hubbard of Ames reviewed the DS2 penetrator design and found four significant problems. 8. (Clawson) We have difficulty getting people to review the “lessons learned” document. 9. (Muirhead, Manning, Lehman) Getting people’s trust is essential if the FBC programs are to be successful. On Pathfinder, they had meetings with everyone, including the fabrication people to tell them what they were doing, to show them the hardware, and to get their support. They saw very little “game playing”; the projects and subsystem developers cooperated very well.	3. (Implied) Gas leakage on a long-term mission can result in gas collecting and condensing in undesired locations. 4. (Implied) A part inherited from a short-term mission where gas leakage may not be a problem can be misapplied on a long-term mission 5. (Implied) An obvious lesson learned was: “Talk to the vendors.” 6. (Implied) Grey beard review can be effective in avoiding “historical” problems. Solicit “outside” assistance. 7. (Implied) Conveying lessons learned is expected by NASA Headquarters. 8. (Implied) Well informed, involved, properly trained people will build a better spacecraft.	7. (Implied) Consider the effect of long term propellant gas leakage and condensation in undesirable locations 8. (Implied) Don’t assume that a successful component inherited from a short term mission will be successful in a long-term mission. This might be generalized to say “Don’t assume that a successful component inherited from one mission will be successful in any other mission without a thorough investigation.” Investigate the environmental differences thoroughly. 9. (Casani) said we need to “skip a generation” of projects and let the people who know the classical problems from the older programs and how they were solved teach the new people. 10. (Someone) How about a comic book on lessons learned? 11. (Cherniak) He has found the “rolling e-mail” message to be quite effective in resolving problems. The message goes from expert to expert and they add their comments. Generally the results have been good. 12. (Clark)Team “K” personnel who go from Phase A project to Phase A project to transfer ideas is an excellent idea. 13. (Muirhead) Incentive to review “lessons learned” has to come from Project leadership. 14. (McKinney) The Magellan report by Ledbetter (JPL D-9643, “Magellan Lessons Learned - Proceedings of the Magellan Lessons Learned Workshop Held December 1991") has an excellent summary of lessons learned on Magellan. Everyone should read it. 15. (Informational) There is also a “Magellan Spacecraft Final Report” (MGN-MA 011), January 1995, prepared under JPL contract number 956700, which summarizes the Magellan history. 16. (Implied) Involve people at all levels to get their trust and make them active team members.

Table 1 Common Threads - Communications (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Inadequate Training of Critical Personnel. Failure to rehearse critical procedures or use the right personnel at the right time.	1. (Spear, McKinney) - Magellan Battery Fire -The battery fire occurred at the Cape. It was caused by an incorrect mating of the battery connector. There were two similar but not identical "scoop proof" connectors, but the connector pins could touch, even though they could not mate. In addition, the connector mating was blind. The mating was done on third shift, and although it was well understood by the day crew, the night crew hadn't been properly trained. The problem was compounded by the mating being upside-down which confused the technician who tried to mate the battery (which was hot) to the wrong connector. 2. (Muirhead) - Pathfinder also had a mismated 28V and 5V connector. This occurred when they interrupted and later resumed a check-out procedure.	1. (Implied) Written procedures are necessary for all critical operations. 2. (McKinney, Casani) Critical procedures must be rehearsed and the people performing them must be trained. 3. (Implied) Interrupted processes are a source of trouble. 4. (McKinney) They have since learned how to charge the NiCad batteries in-place after mating (i.e. no "hot" mating)..	1. (Implied) Look for ways of avoiding critical operations such as mating blind connectors, especially during final launch operations. 2. (McKinney, Casani) Rehearse critical operations. 3. (McKinney) Use the same crew that rehearses. Put *names* in procedures! 4. (Implied) Be especially careful to review system status before resuming an interrupted procedure. Follow the written procedure.
Letting policy rather than considered thought drive critical decisions.	1. (McKinney) Magellan Battery Fire - The thermal blanket wasn't removed at the Cape simply because of a policy issue; there was no technical reason it couldn't have been removed. This would have eliminated the need to mate the battery connector blind.	1. (Implied) Flexibility on policies is required when there is an overriding technical reason for doing so.	1. (Implied) Challenge procedural restrictions when the best interest of the program is at stake. 2. (Implied) This obviously can't be taken to the extreme in which policies are universally challenged, but there are cases in which they should be.
Conveying lessons learned through formal practices documents.	1. Division 34 was said to have a good design practices document. 2. Division 35 does not have a design practices document. 3. Tom Gavin was said to have made a good design practices effort for Cassini as part of Tom Gindorf's Long Life Reliability study team report (JPL D-9899).	1. (Implied) A lab-wide design practices document is needed.	1. (Barela) Need to feed back lessons learned to Design Guidelines. A check list made up from lessons learned might be more useful than the lessons learned database.

Table 2 - Common Threads - Hardware Interfaces

Hardware/Ground Support Equipment (GSE) Interface Problems .	1. (Casani) - Offsetting errors in the flight hardware and its GSE. On the Galileo Probe, two gravity switches were supposed to go off in a particular sequence. The switches were wired backwards, but so was the test equipment. There was an indication of a problem during a centrifuge test, but the flight unit was retested on the GSE and, of course, could not be confirmed. The failure was written off. As a result, the Probe parachute deployed 58 seconds late. 2. (Casani) Using different cables at JPL than at the Cape. They used to use short cables at JPL and long cables at the Cape. Now they use the same cables in both places.	1. (Implied) Offsetting errors in the hardware and test equipment can mask a problem. 2. (Casani) An end-to-end check might have caught the miswired switches on Galileo Probe. 3. (Implied) Beware of “one time” failures.	1. (Implied) Coordinate and peer review the hardware/GSE interface to ensure that assumptions are consistent with system requirements. 2. (Implied) Research ground test failures very thoroughly. 3. Use the same cables at the Cape as at JPL.
Spacecraft/ Launch Vehicle Interface Errors.	1. (Shipley) Different frames of reference for the launcher and the spacecraft - Galileo/Launcher Interface. Galileo was almost launched with the spacecraft and launcher coordinate systems reversed. The AACS could not have recovered from that. At the Cape, they found that the spacecraft and launcher frames of reference were reversed, i.e., one was left-handed and the other right-handed.. 2. (Manning, Muirhead, Lehman) Pathfinder was designed so it doesn’t matter which way the spacecraft is spun off; it can operate in either rotation.	1. (Implied) Errors in the hardware and launch vehicle interface can result in serious failure. 2. (Implied) The Spacecraft/ Launcher Interface should be carefully peer reviewed. 3. (Implied) Sometimes, design steps can be taken to eliminate any concern about differences in the spacecraft and launcher frames of reference.	1. (Casani) - Be especially careful about interfaces of all kinds. In this case, one group of people designed the spacecraft and another designed the launcher. He cited Deming who said “The Devil is in the handover.” 2. (Implied) Coordinate the Spacecraft/ Launcher interface to ensure that the same assumptions are being used on both sides. 3. (Implied) Consider spacecraft designs that are tolerant of either assumption about the launcher coordinate system.
Spacecraft/ Instrument Interface Errors	1. (Miles) Mariner ‘69 A. In-board and outboard temperature sensors were reversed. B. A Vidicon was upside-down C. The planet sensor was reversed.	1. (Implied) Spacecraft/ Instrument interface errors can lead to confusion and potentially incorrect conclusions.	1. (Implied) Perform thorough peer review of spacecraft/ instrument interfaces.

Table 2 - Common Threads - Hardware Interfaces (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Spacecraft/ Simulator interface Errors	1. (Casani) - Galileo RTG - The first time they tried to mount the pressure release device to the RTG (on the launch pad), they thought that the screws had bottomed out. They inserted washers under the screws and flew with only a few screw threads engaged, because they didn't realize the RTG had locking threads. The ICD didn't indicate that locking nuts would be used, and the simulator didn't have them. 2. (Later conversation with Bob Campbell) - Galileo RTG The insertion was done by JPL personnel, even though both pieces of hardware were built by the contractor, because contractor personnel weren't allowed on the Launch Pad. 3. (Casani) Voyager Gimbal Saturation. There were 3 two-axis gyros on Voyager. The gyros all saturated due to roll rate during launch. The GSE didn't have enough output current to saturate the gimbals and the fault algorithms didn't anticipate saturation of all gyros at once.	1. (Casani) - Be especially careful about interfaces of all kinds. Procedures are a good example of a critical interface; they are typically created by one group of people and executed by another. 2. (Casani) "Beware of simulators." - another interface. They are built by one group of people and used by another. 2. (Campbell) Use the right people to do critical operations.	1. (Implied) Peer review of Spacecraft/Simulator interfaces. 2. (Implied) Peer review of ICDs. 3. (Implied) Simulators must simulate both the electrical and physical aspects of the hardware.
Spacecraft/ Handling Equipment Interface Errors.	1. (Casani) The Topex spacecraft, being lowered into a thermal/vacuum chamber, was turned over 135^{o} and nearly dropped by the handling equipment at the contractor's facility. They had standard procedures for designing stable lifting devices but didn't follow them.	1. (Implied) Involve system safety people in the review of handling operations. 2. (From JPL LL) Analyze inherited handling equipment whenever it is to be used in any new application. 3. (Implied) Follow approved written procedures for all spacecraft handling operations.	1. (Implied) Peer review of all spacecraft handling procedures, including participation by system safety personnel. 2. (From JPL Lessons Learned) Ensure qualified, experienced personnel perform critical, hazardous operations.

Table 3- Common Threads - Interfaces - Contractual

Common Thread	War Stories	Lessons Learned	Corrective Strategies
JPL/Contractor relationships have had a spotty history; some work well, others have not.	1. (Cunningham) - Mars Observer - Fixed Price Contracts. They attempted to do a fixed price contract, but with award fee provisions. The fixed price part led to problems when design mods were required. .2. (Wright) Performance-based contracting is having an effect on the lessons learned issue. JPL necessarily takes a more “hands off” approach and is not as intimately involved in the day-to-day technical issues. We are very dependent on the contractor for sharing lessons learned information. 3. (Pace) MO/MGS A. The JPL attitude was that the MO failure was the contractor’s fault. This is not the case. Pace felt that the Lab never bought into the MO design. On MGS, they built a team, and this has worked much better. (1) - MGS They had a retreat with the JPL and contractor personnel; this set the framework for the future and improved cooperation. (2) - MGS They maintained JPL people on-site at the contractor which facilitates problem solving 4. (Shipley) Magellan was a special case in which the partnership worked well. Magellan benefitted from experienced contractor personnel from the Viking program being transferred to Magellan	1. (Implied) Be especially careful with fixed price contracts. They can lead to the contractor and JPL working at cross purposes, especially on mods. 2. (Wright) Performance-based contracting can make a contractor less willing to share lessons learned information. (Implied) This applies to sharing current failure information as well. 3. (Pace) Developing good working relationships with the contractor pays dividends 4. (Implied) Working with a contractor over a long period allows the contractor to develop the necessary skills mix. 5. (McKinney) There needs to be a mix of “new blood” and “old hands.”	1. (Implied) Develop a good working relationship with the contractor. 2. (Cunningham) suggested a contracting mode of a fixed price spacecraft development with a CPAF contract for ATLO. 3. (Pace) MO/MGS A. It is important to match the JPL organization to the contractor organization, so there are direct counterparts to solve problems. .B. Visit the subs. Let them meet with the program people. They love it. 4. (McKinney) A small, focused, motivated and co-located team is better at producing one-of-a-kind spacecraft than a formal, rigidly structured system that tries to force out a quality product. 5. (McKinney) Work at team building. Keep the team focused. Get all members involved. 6. (McKinney) The team must believe in the schedule. Don’t be afraid to replan. 7. (McKinney) Don’t study the program to death. Make the easy decisions and save your energy for studying and planning the hard ones.
The prime contractor generally lacks the technical depth of JPL.	1. (Shipley, Cunningham) - Mars Observer Program - The spacecraft contractor was pretty autonomous from the JPL Program Manager. JPL had less control. 2. (Cunningham) There was some loss of contractor systems engineering capabilit. They could do “cookie cutter” spacecraft pretty well, but mods to the mission caused problems because they lacked depth. 3. (Cunningham) Where there were significant changes in the hardware and the mission, they didn’t do as well	1. (Implied) Contractors can lack technical depth in dealing with significant changes to the hardware or mission.	1. (Implied) JPL needs to be involved and provide its unique expertise in the contractor’s decisions

Table 3- Common Threads - Interfaces - Contractual (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Allowing the contractor to proceed on remedial action without a formal funding mod.	1. (Cunningham) - Mars Observer Contract. The spacecraft contractor was permitted to proceed with changes without firm negotiations of contract mods, cost and schedule. Actual costs were significantly greater than estimated costs.	1. (Cunningham) Costs get out of control if a contractor is allowed to proceed without agreed-upon corrective action, cost and schedule. 2. (Cunningham) Timely contract mods during S/C development are essential.	1. (Cunningham) It is important to have timely approval of contract mods, if cost and schedule are to be controlled. 2.(Cunningham) A CPAF contract for ATLO might facilitate remediation and eliminate the need for numerous contract mods.
Changing the Product Assurance requirements during the course of a development contract.	1. (Cunningham) Mars Observer saw an increase in JPL-imposed product assurance requirements on inherited hardware. Because this led to physical changes in the hardware or processing (Implied), Cunningham felt that this tended to violate inheritance as well as increase costs.	1. (Implied) Runaway requirements changes during spacecraft development can lead to uncontrolled costs .2. (Cunningham) observed that the JPL culture which is geared to change and innovation has difficulty dealing with a program like MO that is intended to use mostly inherited hardware.	1. (Implied) Up front review of inherited hardware by Product Assurance to scope the impact of PA requirements. Include them in initial planning. 2. (Cunningham) Future programs must recognize the difference in “high inheritance” programs and make appropriate changes in JPL technical and management culture for those programs.

Table 4 Common Threads - Heritage and COTS Issues

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Placing too much trust in inherited hardware.	1. (Shipley) Off-the-shelf Hardware We tend to trust inherited hardware, but inheritance is just another interface to be managed. Some sages say that "the only thing that's any good off the shelf is when it's off your own shelf" or "the only thing you getoff the shelf is dust." 2. (Cunningham) - Mars Observer Failure - They inherited a propulsion system (PS) from an earth orbiter in which the PS was required to function early in the mission. They applied it on MO and expected it to operate after a long cruise phase. Long term propellant gas leakage was the most likely cause of the MO failure. 3. (Shipley) - Commercial-Off-the-Shelf (COTS) Hardware -. The odds are that when you use COTS, a WCA or stress analysis will *not* have been done. 4. (Cunningham) MO was to be the first in an "Explorer-like" line, i.e., a series of very similar spacecraft. Instead, it turned out to be the only "observer" spacecraft. They assumed they would have simple inherited instruments. They also assumed that they would make maximum use of contractor inheritance (hardware, personnel, procedures, product assurance). Instead, they found that high heritage instruments were not available. He rated the quality of the inherited instruments as only B to B+.	1. (Implied) Use the same level of scrutiny on inherited hardware as used on new hardware. 2. (Implied) Environmental and mission differences may make inherited hardware inappropriate for a new application. 3. (Cunningham) Making too many changes tends to cancel out the added value gained by using inherited hardware.	1. (Shipley) "Test the Devil out of inherited hardware." 2. (Implied) Perform an intensive review of the mission differences between the donor program and the recipient program. 3. (Implied) Don't assume that inherited hardware is O.K. Analyze it, and if the new application is significantly different, test it as if it were a new design. You may have to do WCA and stress analysis on it also.
Trying to make something that's good enough "a little better".	1. (Spear) - Magellan CDS Even when hardware is inherited, something changes. Magellan inherited the Command Data System from Galileo, but with entirely new software. He likened spacecraft to race cars - "Every one is unique." 2. (McKinney) - Magellan SRM S/A Switch. They modified a proven Solid Rocket Motor Safe/Arm (SRM S/A) device to add independent redundancy, but the technicians had never seen the unique design and miswired it. McKinney said this almost cost them the mission. They were saved by an SRM contractor engineer who had second thoughts about whether he had done it right and rechecked it. 3. (McKinney) - Magellan Transmitter. The supplier had experienced a grounding problem with the transmitter. They came to the prime contractor with a mod to change the ground strap. The mod was made, but the unit was flown with less than 100 hours of test time on it. A chip capacitor damaged during the rework failed causing degradation of the "B" channel X-Band transmitter.	1. (Implied) It is easy to overlook critical issues when "improving" inherited hardware. Critical design issues that were understood by the original designers may be overlooked in the redesign. 2. (Implied) If it ain't broke, resist the urge to fix it. 3. (Implied) Use experts to review processes and procedures.	1. (Implied) Perform a critical review of any modifications to inherited hardware. Include design, environmental, and handling issues in the review. 2. (Implied) Solicit expert peer review wherever possible. 3. (Implied) Weigh the risks of modification against the benefit of the change.

Table 5 - Common Threads - Parts Issues

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Lack of Flagship programs to fund major new parts developments.	1. (Wright) Space programs now follow rather than lead the semiconductor market. 2. (Wright) Projects with tight funds and schedules cannot expect to participate in a lot of new technology development and succeed. That is not to say that new technology should not be used. 3. (Manning, Muirhead, Lehman) - Pathfinder How is JPL going to do the small projects without the flagship programs? They gained a lot by getting custom ASICs from Cassini. . 4. (Cherniak) Failure to replenish the heritage is a major problem. There are lots of small issues in addition to parts in which the infrastructure is not being stroked.	1. (Wright) Semiconductor process development is likely to be incompatible with a spacecraft project schedule, especially on FBC programs. 2. (Wright) Low volume production is a special problem. 3. (Wright) Custom designed parts can be compatible with a project's resources if their processes are under good control and the designs don't push the technology too far. 4. (Wright) Overall we should be able to exploit the microelectronics revolution to achieve small, very capable, highly reliable spacecraft.	1. (Manning, Muirhead, Lehman) One of the best ideas is the strategic stockpile. It turns out to be good for both programs if some extra ASICs are built at relatively low cost and then sold back to a later program. The second program gets custom ASICs at much lower cost and doesn't have to finance a development. The earlier program can recoup some of its development costs from the later program. 2. (Earl Cherniak) is working with Code S to get support for the strategic stockpile 3. (Wright) When you are tempted to or must develop enabling technology: A. Work hard to find some alternative or at least a bail out position. B. Make an excruciatingly detailed assessment of the risk associated with the development. C. Set aside reserves (funds and schedule) commensurate with the risk assessment (be generous). 4. (Wright) Consider pooling resources of several small projects to fund technological advances that are useful to both.
Parts Qualification Issues	1. (Manning) It is a "big mistake" to simply go with commercial parts or MIL parts. It is O.K. to upgrade MIL parts if they are upgradable, but don't simply accept the MIL part without evaluating it in the application. 2. (Wright) Sometimes the question is asked how the auto manufacturers are able to achieve spacecraft quality levels with "commercial" parts. He considers it a myth to equate the quality of the auto manufacturers' semiconductors with "commercial" part quality. The auto industry buys in huge quantities and dictates any special screening and testing they want. JPL never has that luxury. 3. (Wright) Plastic parts are probably O.K. in space if we can get them there intact. Don't kill them on the ground with cleaning and handling. Inherent reliability is not a problem.	1. (Wright) Parts without fully developed and demonstrated fabrication processes should not be in a spacecraft design 2. (Wright) said that thorough JPL testing of ASICs should continue, because they are custom devices, and there is little or no other basis to confirm the quality and functionality of the product	1. (Manning) - Pathfinder They did an analysis of all of the parts and the system effects if they should fail. He didn't mention a formal FMEA, although the process seems to be similar. 2. (Wright) Continue JPL testing of ASICs to confirm the quality and design. 3. (Wright) Plastic parts may become a reality on FBC programs, providing acceptable quality at lower cost.

Table 5 - Common Threads - Parts Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Misapplication of parts.	1. (Shipley) - Voyager 2 A polycarbonate capacitor in the receiver tracking loop shorted. It was an obvious misapplication of the part, because polycarbonates were known to develop dielectric shorts at impurity sites. In a high voltage application, a high current discharge occurs which clears the short, so they are self-healing. In a low voltage application, the self healing doesn't occur and they stay shorted. In the Voyager case, the uplink center frequency had to be continuously shifted to track the meanderings of this capacitance. 2. (Wright) On the plus side, parts reliability is getting better, and failure rates for commercial ICs in the 90's are as good as S-level parts were at the beginning of the 80's.	1. (Wright) All designs are not created equal. "Parts" problems can always be created by misapplication and bad packaging practices. 2. (Wright) Reliability of semiconductor parts is improving rapidly, but misapplied parts still fail. 3. (Wright) Parts still fail by the same old failure mechanisms, but they don't fail as often because semiconductor processing is being continuously improved.	1. (Implied) Pay close attention to "physics of failure issues. 2. (Wright) The semiconductor manufacturers have "bug books" that tell the idiosyncracies of their parts. They will generally make them available on request. These "bug books" can help designers avoid part misapplication 3. (Informational) Section 505 has an RTOP pending which will investigate ways of incorporating "physics of failure" issues into FMEAs and FTAs.
Parts Availability and Delivery Problems	1. (Cunningham) - MO The "Just in Time" (JIT) procurement philosophy resulted in unavailability of parts at the Cape, because they weren't in stores. 2. (Wright) Semiconductor process development is likely to be incompatible with a spacecraft project schedule, especially in the FBC programs. 3. (Wright) There is often inadequate planning for "normal" procurement times. Some "commercial" parts can take a year. JAN-S and Source Control Drawing (SCD) parts can take up to two years.	1. (Wright) Projects have to work with the parts people in ordering parts early and whenever possible ordering off-the-shelf parts. 2. (Wright) Shouting louder rarely improves schedules.	1. (Wright) Work with the parts people and order parts as early as possible. 2. (Wright) Plan for procurement delays associated with S-level and SCD parts. 3. (Implied) Review JIT procedures to make sure any anticipated parts needs can be filled expeditiously.
Proper amount of burn-in time.	1, (Shipley) All of the Voyager hardware had 1200 hours of test time. The back up had 1500 hours. 2. (Muirhead) Pathfinder has over 2000 test hours on everything in the spacecraft. 3. (McKinney) - Magellan The Proto flight unit went through the entire environmental sequence. They flew it and the tape recorder failed within a week. 4. (Clawson) 5X is recommending at least 500 hours on all flight hardware.	1. (Wright) When asked whether the 2,000 hour testing on Pathfinder flight hardware was a good idea, Wright said he was convinced it was but that he couldn't prove it.	1. (Group) The consensus was that the flight unit should have as much ground test time as possible. Product Assurance recommends no less than 500 hours; the projects have used up to 2000 hours.

Table 5 - Common Threads - Parts Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Unique Part Types are a Problem.	1. (Shipley) Hybrids have always been a special problem. 2. (Shipley) MCMs are likely to be a problem also. 3. (Wright) Special builds are a special problem	1. (Shipley and Wright) Hybrids and special builds have unique problems. 2. (Shipley) MCMs are another hybrid, so expect problems with them too.	1. (Implied) Anticipate problems with hybrids, MCMs and special builds and allow sufficient budget and schedule reserves for them.
Radiation Environments are a special problem.	1. (Wright) Radiation and SEE environments are unique to space and DoD programs. 2. (Wright) Obtaining hard semiconductors is becoming increasingly difficult, because DoD is not supporting new developments as it has in the past. 3. (Muirhead) SEU was handled at the system level though SEU-tolerant design features (reset, etc.) which is effective, so long as the parts don't get destroyed by the radiation or permanently latch up.	1. (Wright) New programs will experience difficulty in obtaining hard parts. 2. (Implied) Design around SEE effects at the subsystem or system level, if possible.	1. (Implied) Purchase and qualification of specific lots to radiation environments may be a solution. 2. (Implied) Design SEE tolerance at the subsystem or system level.
Discretes and Passive Parts.	1. (Wright) Discretes and passive parts are becoming an increasing problem, both in quality and availability - largely due to reduced usage in the commercial marketplace.	1. (Implied) New programs may experience delays and quality problems with discrete components.	1. (Implied) Expect to do more internal "qualification" through lot screening, incoming inspections and special environmental tests.

Table 6 - Common Threads- Programmatic Issues

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Growth in science requirements that jeopardize the mission.	1. (Cunningham) - Mars Observer They assumed there would be focused science, i.e., the experiments were well understood and would not change. Instead imaging was added, which used up all spacecraft resources until no margins remained. 2. (Cunningham) - Mars Observer There was low resistance to changes on the program, and that they backed down on the science too much. He said that even though the Lab Director did not support increased science, the PI went to NASA and brought pressure to increase science.	1. (Cunningham) The project office has to be firm in resisting changes that will result in cost/schedule impacts.	1. (Group) In lieu of the elimination of the Flight Programs Office (FPO), some union of Project Managers might be effective in coordinating science requirements across several programs and reducing the impact of science growth on a single program. 2. (Cunningham) Recommended that the Project Office have a part in payload selection. In this regard, he said that in FBC programs cost had to be paramount, outweighing performance, in trade off studies.
Discarding the “old way” on FBC programs simply because it’s old.	1. (Cunningham) observed that the people in charge of implementing new faster-better-cheaper guidelines on new programs tend to reject the “old” just because it’s old. 2. (Clawson) added that we have to walk a careful line. New people generate new ideas. When we get locked into things just because they were done before, we generate a lot of baggage. We have to find a way not to lose lessons, but still not dampen enthusiasm for the new.	1. (Clawson) New programs must strike a balance between historically proven methods and innovation.	1. (McKinney, Clawson) New programs need a mix of personnel and ideas: Old hands, familiar with historical problems and new people, familiar with the latest technology.
Unstable funding environment driving program decisions.	1. (Cunningham) - Mars Observer They assumed a stable funding environment, but the Challenger incident resulted in significantly reduced funding. 2. (Cunningham, Shipley) Because of turnover at NASA HQ, about once every 3-4 years, there is a change in mind set. On long programs, you can’t assume that people who make agreements will be there to honor them when the time comes.	1. (Cunningham) It is important that reasonable cost estimates and margins of error be considered early in the program to ensure adequate funding.	1. (Cunningham) Recommended that up front agreements on costs be made with NASA headquarters, the science community and JPL support organizations.
Failure to consider the importance of assumptions and failure to replan when the assumptions change.	1. (Cunningham) - Mars Observer Contrasted the assumptions at the beginning of the MO program with the realities which occurred during the program. There were many disconnects. He felt that the project had failed to question the reality of the basic assumptions.	1. (Cunningham) It is necessary to replan when fundamental assumptions change.	1. (Cunningham) Recommended that all assumptions be reviewed early in the program, and that fall back positions be developed for scenarios in which the assumptions fail.

Table 6 - Common Threads- Programmatic Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Increased “sell” pressure on programs, to provide more performance at reduced cost on tighter schedules.	1. (Spear) Mars Pathfinder Spoke about the complexities of Pathfinder. He said there are actually three spacecraft in one, making it very complex. 2. (Spear) Expect intense competition from other centers. There will be strong pressure to sign up for more challenging missions. There will be lots of technology innovation with corresponding pressure on cost and schedule. He mentioned: A. Low cost Mars Orbiter and Lander B. High speed surface penetrator C. Remote Agent and Autonomous Navigation D. Solar-electric propulsion E. Solar array collector F. Star Dust Sampler 3. Spear considers DS1 the riskiest mission JPL has ever done. 4. (Pace) MO They found that program metrics were useful. The metrics tracked were the boards built for ATLO and schedule margins. 5.(Shipley) JPL is always two failures away from being shut down. Some of the other centers have less visibility, but all of JPL’s programs are high visibility. 6. (Shipley) Voyager They asked for parts lists from the instruments before they were permitted on-board. Because of the radiation requirements, this separated the well conceived and “heritage” instruments from the poorly conceived ones which helped to control costs. 7. (Muirhead, Manning, Lehman) Getting people’s trust is essential. On Pathfinder, they had meetings with everyone, including the fabrication people to tell them what they were doing, to show them the hardware, and to get their support. They saw very little “game playing”; the projects and subsystems developers cooperated very well.	1. (Shipley) We need to maintain JPL’s reputation of delivering on its promises. 2. (Shipley) It’s sometimes necessary to go back to NASA Headquarters and fight back. 3. (Cherniak) There are some “lines in the sand” that have to be drawn. There are issues that can’t be compromised in the name of FBC. 4. (Manning) Getting people’s trust at all levels can make the difference in	1. (Pace) Recommended use of dollar reserves in this priority: A. mission-critical capabilities B. .minimize risk C. cost containment 2. (Shipley) Project Managers have to get their problems understood by upper management. Communicate that the demands may be unreasonable. This needs to be done in some structured way. We need to get this picture to the Director. 3. (Shipley) Maybe it is necessary to re-establish an FPO to coordinate projects and science to reduce the “sell” pressure on individual programs.
Program Reviews .	1. (McKinney) 90% of the value of a program review is in the preparation for it. New FBC programs seem to be going to shorter reviews. This could be a mistake.	1. (McKinney) FBC Programs could benefit from longer program reviews, more accurately, the preparation associated from longer reviews. 2. (Implied) The greatest value comes from peer reviews.	1. (Implied) Make sure that the content of program reviews forces the right level of preparation, even for the FBC projects. 2. (McKinney) Keep the action items from a review to a manageable few.

Table 6 - Common Threads- Programmatic Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Sparing Policy	1. (Pace) MO/MGS MGS couldn't have done it without the MO spares. 2. (Pace, Shipley) Less than 10% of missions need to fly a spare (defined as changing it out at the Cape), but you never know which ones. "You do what you have to do to fly the flight unit and avoid using the spare." Some examples: A. Viking flew a spare propulsion system B. Voyager flew a spare AACS C. Mars Observer Camera - Switched boards prior to launch D. Several flight units fixed or repaired at the last moment. 3. (Pace) Spares keep the test program going. 4. (Shipley) Voyager had three sets of spares; this was very powerful. 5. (Muirhead, Manning, Lehman) You can't have too many spares. 6. (Casani) You probably don't have time to switch out the flight unit for the spare at the Cape anyway with current scheduling.	1. (Implied) FBC programs will have to develop creative ways of sharing spares. 2. (Implied) Generally speaking, the more spares, the better.	1. (Pace) Try to spread spares over multiple programs. 2. (Cherniak, Others) Try to get Code Q to support the strategic stockpile with parts and some assemblies.

Table 7 - Common Threads - ATLO and Launch Site Issues

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Correct amount of time for ATLO on an FBC Program	1. (Manning) - Pathfinder Said that they used "defensive design" principles. They always asked the question: "How are you going to test whatever you design into the hardware?" They forced the subsystems to deliver early to gain ATLO schedule margin. They gained a lot by adding tests during the course of the test program. They built in lots of schedule and cost margin: 18 month ATLO and 50M contingency on a 150M program. 2. (Manning) - Pathfinder They thought the test bed would be sufficient; it took them a long time to realize it wasn't. They didn't spend a lot of time planning the test program. They made quick decisions and added tens to hundreds of tests. Still there were some tests they could not do in an earth environment. 3. (McKinney) - Magellan Challenger caused a launch schedule slip. His opinion is that they wasted a year of the delay running in place. The point was that there was plenty of time to correct problems, but it wasn't done.	1. (Spear) - Pathfinder An 18 month ATLO was essential to the program. 2. (McKinney) - Magellan A 12 month ATLO is about right. Plan for 2 shifts, 5 days a week, but budget for 3 shifts, 6 days a week. 3. (Wirth) If the people, parts and processes are unknown, ATLO may take 18 months, but as these are better understood it can be as short as 12 months. 4. (McKinney) Do just the right amount of early planning. Too much early planning is a waste of valuable resources.	1. (Implied) Use defensive design procedures. Ask "How will we test this mod?" 2. (Implied) Leave room to add tests during ATLO. Provide schedule and cost margin to do so. 3. (McKinney) Don't over plan 4. (Wirth) Plan for a 12 to 18 month ATLO, depending on how well people, parts and processes are understood.
Moving to the Cape with incomplete procedures and without the necessary personnel to make decisions quickly.	1. (Spear) There is always a "crunch" at the Cape. No matter how much you plan, something is always overlooked. 1. (Cunningham) - MO They moved from the factory to the Cape without complete procedures. Key personnel weren't always available at the Cape which delayed decision making.	1. (Implied) Check out the GSE and procedures early to avoid delays at the Cape.	1. (Cunningham) Get the Cape procedures done early. Allow time to shake out the procedures and GSE thoroughly after moving to the Cape.
Failing to plan for delays at the Cape.	1. (Cunningham) - MO MO experienced delays due to weather which weren't planned for. 2. (Cunningham) - MO Mentioned the impact of a new launch pad which was built at the Cape just before MO launch and led to increased contamination and delays.	1. (Implied) Weather delays happen at the Cape and should be included in contingency planning.	1. (Cunningham) Contingency planning should be done for possible delays at the Cape.

Table 7 - Common Threads - ATLO and Launch Site Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Safety issues.	1. (Spear) - Mars Pathfinder They failed to consider safety adequately on Pathfinder. They dropped a piece of ballast into a vegetable truck during balloon testing of the descent parachute. There were no injuries but some remedial costs and embarrassment.	1. (Implied) Don't overlook safety issues in test planning.	1. (Implied) Involve safety people in test planning.
Failure to consider the differences in the test environment and the flight environment.	1. (Casani) - Mars Observer HGA Talked about the difficulties of testing in gravity vs. the space environment. He cited a cable on the Mars Observer HGA that was supposed to fall into a V-notch, which it always did in gravity, but in zero-g, it fell outside the notch and got in the way of a latching fork.	1. (Cherniak) Test it like you are going to fly it. (Implied) - When you can.	1. (Cherniak) Whenever possible, test it like you're going to fly it. 2. (Implied) Consider the possibility of differences in operation in zero-g environment.

Table 8 - Common Threads - Product Assurance Issues

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Runs of “bad luck” when Product Assurance controls/policies slacken.	1. (Spear) - Mars Pathfinder Said that there will be less oversight and fewer checks and balances on FBC programs. This will put increasing pressure on 5X to come up with ways to provide just the right level of oversight in an environment characterized by shrinking funds. 2. (Spear, Muirhead, Pace) Praised the concurrent/collocated approach for the whole design team that was used on Mars Pathfinder and MGS. The product assurance personnel have made a valuable contribution to the program effort working in this mode. 3. (Muirhead) They did a top-down reliability analysis on Pathfinder. They tried to anticipate the potential reliability problems. They made a conscious effort not to micro-manage, but they made it a point to “micro-understand.” 4. (Shipley) There has always been a conflict between trust and structure. He reviewed some of the history of reliability issues at the Laboratory. He started back in 1944 with the first JPL Director, Frank Molina’s policy on the Sergeant missile program. Molina distributed a memo that 5 units of every subsystem would be tested prior to deployment. Molina’s memo was just ignored. The colonel in charge of the Sergeant program attitude was “Trust them, they do good work.” 5. (Shipley) The Ranger program had no reliability requirements. They did pretty much the same thing, i.e., without formal PA controls, that they had done on Sergeant. The P/FR system was voluntary. The first five Ranger flights were failures. On Ranger 5, there was a massive power short. A rubber washer relaxed over time and came off causing the short. They had stopped doing a system-level vibration test, which might have caught the failure. 6. (Shipley) recounted how Jack James came in later with an Environmental Program Plan. James imposed a stricter environmental test program on Mariner 62. This was the beginning of the Program Documents (PD).. 7. (Shipley) When asked how one validates a system design, Shipley used an analogy with his Catalina boat. Every one is designed by the company owner, an experienced sailor, who knows how things should be laid out. As a result, everything is in its proper place on a Catalina boat and it is all due to the skill of the designer. 8. (Shipley) JPL got away without doing worst case analysis (WCA) up through Viking, but they were saved by wide temperature margins between the hardware test and actual space environments. 9. (Shipley) They couldn’t avoid WCA on Voyager because of the radiation environment. 10. (Muirhead) Pathfinder used a hot temperature margin test, generally in lieu of a WCA.	1. (Spear) 5X is challenged as never before to provide the proper oversight on FBC programs with few other checks and balances. 2. (Shipley) There is a strong relationship between adequate product assurance controls and successful programs. When things go wrong, they go very wrong. 3. (Observation) Some programs are attempting to use voltage-temperature margin tests as a substitute for WCA. This can have pitfalls, especially if there is a radiation (or long life) requirement. 4. (Spear, Muirhead, Pace) Collocation of product assurance personnel seems to be working well.	1. (Implied) Collocation of product assurance personnel seems to be working; it should be encouraged on future programs. 2. (Implied) Don’t let our guard down. Even with the FBC initiatives, there must still be strong Product Assurance. JPL’s reputation demands it. 3. (Shipley) How do you validate a system design? Experience. 4. (Implied) When funds are tight for product assurance, place increased emphasis on peer review to avoid problems. 5. (Implied) Up-front consideration of potential reliability problems will pay dividends. 6. (Implied) Voltage-temperature margin testing may be considered as a possible replacement for WCA in some applications, but beware of radiation and long life requirements.

Table 8 - Common Threads - Product Assurance Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Runs of “bad luck” when Product Assurance controls/policies slacken. (Continued)	11. (Shipley) said that when things get bad, they get really bad. Goddard has had strings of failures during periods when they let down on requirements. They can get away with more, because they get less public scrutiny than JPL. JPL has visibility to the whole world. The interplanetary missions tend to be watched by the whole science community and the public. As a result, JPL has to be more cautious. 12. (Shipley) JPL may be in the middle of this cycle with Mars Pathfinder and 4 or 5 follow on projects with all of the “sell” pressure on the lab. 13. (Barela) Likened the current situation to a pendulum that has swung from a primarily prescriptive process to one of “do the right thing”.	(See above)	(See above)
JPL’s reputation generally dictates that Class A, B, C, D missions still have the same success expectations.	1. (Muirhead, Lehman, Manning) - Mars Pathfinder “Once you’re in ATLO, everything is Class A.” 2. (Manning) Don’t skimp on QA. The rover and flight computer lost CCDs due to electrostatic discharge (ESD). They should have allowed for more QA.	1. (Implied) As a result of JPL’s reputation, program success expectations are very high even when the budget isn’t. 2. (Manning) Don’t skimp on QA.	1. (Spear, Others) Get as much ground test time on the flight unit as possible. 2. (Shipley, Others) Adequate margins cover a multitude of sins.
Chronic problems with “low end” failures.	1. (Earl Cherniack) Served on a review board for an SDIO program that had gotten into a lot of trouble because they ignored lessons learned on earlier programs. It was little things that caused the program’s difficulties, problems that should have been well understood and had been solved before. 2. (McKinney) We need to figure out a way to build a good flight harnesses. 3. (Casani) We continue to have problems with “low end failures;” bent pins, potting of relays and transformers, building flight harnesses, etc.	1. (Implied) JPL and other centers still have chronic problems with low end failures. These are manufacturing and QA problems which have practical solutions in-place, but the skill and care get lost from one program to the next.	2. (Implied) Involve peer review in manufacturing and QA processes. This is a situation in which, prior experience is essential in making sure the chronic problems are (remembered), understood and dealt with.

Table 8 - Common Threads - Product Assurance Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Usefulness of Waivers as a means of improving reliability.	1. (Shipley) Strongly believes in waivers. Waivers force people to write down what they think. In a meeting, people will agree to something without giving it proper thought. Later, when they are forced to write down the rationale for the decision, they often see how bad the idea actually was. Waivers also provide a history of what the thinking was when issues are reconsidered later for some additional waiver. This often gets lost, and other waivers are granted, even though they violate the assumptions made for the first one. 2. (Shipley) Admitted he had probably signed some waivers he shouldn't have. On Voyager, the Thruster T/V test was waived. 3. (Shipley) People at JPL are inherently opposed to waivers. They would rather delete a requirement than process a waiver. 4. (Shipley) Galileo Antenna Damage during Environmental Test - They didn't write a waiver, although they were deviating from lab policy. If they had, the antenna damage which occurred during the test would probably have been avoided. 5. (Shipley) On the TOPEX program, Bud Powell and Teo Almaguer reviewed all the waivers weekly, just to make sure that some important assumption didn't fall through the cracks. By the end of the program, they saw the value of it and considered it very important.	1. (Observation) There was not universal agreement on waivers. The more recent projects are writing fewer waivers in an effort to reduce costs. 2. (Shipley) The formalism of writing and approving a waiver can uncover serious problems with the thought process involved.	1. Ongoing review of waivers and their underlying assumptions has been found to be an effective way to manage the risk associated with waivers.
Overly-complex fault protection circuitry and inadequately tested fault detection algorithms.	1. (McKinney) - Magellan The Magellan flight software was delivered late, and incompletely tested. They couldn't test it all at the system level. They weren't sure what it would do in all cases. McKinney's opinion is that "we dodged a bullet" 2. (McKinney) - Magellan He said they didn't fully understand the Read Only Memory (ROM) safing issue. 3. (McKinney) - Magellan Cited a software problem that occurred during ground test, but the P/FR wasn't closed; then it occurred later in flight.	1. (McKinney) He believes that fault protection is getting too complicated; it is not fully understood and there is too much fault protection. 2. (Implied) Beware of the anomaly that occurs only once pre-launch; it can occur again in flight.	1. (Implied) Include fault protection algorithms, but only to the extent they can be fully understood and tested before flight. 2. (Implied) Investigate "one time" failures very thoroughly before deciding they won't happen again in flight.
EMI/coupling and grounding problems.	1. (Shipley, Wirth) - Viking?- A remote power-on was added to power up the spacecraft on the launch pad. When the 100 Watt audio Public Address system was turned on, the spacecraft turned on too due to electromagnetic coupling of the signals in the cables. 2. (McKinney) We know how to do a "perfect" grounding system. We don't know how to do a grounding system that is just "good enough."	1. (Implied) EMI and Grounding problems do exist and need to be considered. 2. (Implied) EMI expert review is about the only feasible way of ensuring that good EMI and grounding practices are used. 3. (Implied) Some degree of "overkill" is probably inevitable in developing a clean grounding system.	1. (Implied) Involve expert peer review in establishing a clean grounding system. 2. (Implied) Use commonly accepted grounding practices, available through several government and commercially available publications.

Table 8 - Common Threads - Product Assurance Issues (Continued)

Common Thread	War Stories	Lessons Learned	Corrective Strategies
Learning the right way to do something *after* a failure has occurred.	1. (Shipley) Mentioned the Drop Physics Experiment in which a WCA was done *after* it had failed. The WCA proved that the power supply wouldn't work. 2. (McKinney) - Magellan - After launch, they found an alert against a capacitor that McKinney thinks may be involved in the degraded tape recorder performance.	1. (Implied) Hindsight is 20:20. 2. (Implied) There is no substitute for anticipating likely problems and taking preemptive measures to avoid them.	1. (Implied) Review parts lists against GIDEP to see that all generally known propensities for part failure are understood and the risk accepted.
Overkilling a problem, e.g., through too many "Tiger Teams".	1. (McKinney) - Magellan Battery Fire. McKinney felt that there was too much investigation of the Magellan Battery fire. The failure mechanism was easily discernable, and there was no need for extensive investigation by a Tiger Team. 2. (McKinney) - Magellan Thermal Problems There were lots of thermal problems on Magellan. In-flight temperatures were higher than they had anticipated in several places, e.g., the Rocket Motor nozzle, Optical Solar Reflector (OSR), Thermal Structure, etc., but there was adequate thermal margin. They solved most of these by reorienting the spacecraft and through various Mission Operations. The bottom line was they still exceeded the mission requirements, mapping over 95% of the surface of Venus.	1. (McKinney) Mistakes happen. Don't let the failure investigation detract from other more essential program priorities. 2. (McKinney) On a non-autonomous spacecraft, you can solve a lot of problems through mission operations.	1. (McKinney) "Stay Humble." Sometimes the best answer is no "Tiger Team".
Incomplete grasp of the underlying "physics of failure".	(McKinney) - Magellan The Magellan Star Scanner tracked some particles which it mistook for stars. They were believed to be spalled off the thermal blanket. McKinney said they were missing a lot of understanding of the related physics. He asked: "Do we know how materials interact?"	1. (McKinney) Don't use Astroquartz may be a good idea, but it isn't the entire answer.	1. (Implied) Don't use Astroquartz. 2. (Implied) We need to continually improve our knowledge of physics of failure in order to develop the right solution to problems.
RTOP Strategies	1. (Clawson) Discussed the current RTOP thrusts and strategies. The objectives are: A. Developing more focused testing programs that are effective but are faster and cheaper. B. Developing guidelines for New Millennium risk tradeoffs and optimizing the Prevention, Analysis, Controls and Test (PACT) measures used on the New Millennium missions. C. Examining flight performance for "common threads" and carrying forward solutions that have worked to new programs. D. Providing a vehicle for documenting heritage data on NASA hardware		1. (Implied) The Mission Assurance RTOP thrusts are intended to assist projects by improving product assurance analyses and test programs, based on lessons learned and flight experience.

Acknowledgments

The following persons made presentations of common thread “war stories” to the group and are quoted throughout the Discussion section of this report:

John Casani
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